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Multi-criteria decision analysis and cost–benefit analysis of alternative scenarios for the power generation sector in Greece

D. Diakoulaki*, F. Karangelis

Department of Chemical Engineering, Laboratory of Industrial and Energy Economics, National Technical University of Athens, Zografou Campus, 15780 Athens, Greece

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Abstract

This paper examines four mutually exclusive scenarios for the expansion of the Greek electricity system developed by official authorities and representing alternative views on meeting electricity demand. The aim is to encompass all positive and negative side-effects characterizing the electricity generation technologies assumed to participate in each scenario and emphasis is given to the particular role of renewable energy sources which represent a major differentiating factor between them. The calculation of economic, technical and environmental performances of the examined scenarios for the year 2010 shows that electricity planning is a complicated task since improvements in one policy target are accompanied by losses in others. In order to resolve this conflict, the scenarios are comparatively evaluated with two decision support techniques, multicriteria decision analysis and cost–benefit analysis, which are capable of broadening the strict boundaries of a financial analysis while avoiding intuitive solutions that are often applied in practice. Following the two completely different evaluation approaches, it is confirmed that the scenario assuming the highest penetration of renewable energy sources is the best compromise configuration for the Greek power generation sector.

Keywords: Renewable energy; Scenarios; Electricity; Multicriteria analysis; Cost–benefit analysis

*Corresponding author. Tel.: +30 210 7723 254; fax: +30 210 7723 155.
E-mail address: diak@chemeng.ntua.gr (D. Diakoulaki).

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Contents

1. Introduction

Scenarios are widely used to predict the future evolution of energy systems and assess their economic and environmental implications. Alternative scenarios for the same system are intended to illustrate the impact of different energy and technology mixes on the type and intensity of these implications. Specific emphasis is recently put to the role of Renewable Energy Sources (RES) which are recognized to significantly contribute to the reduction of environmental repercussions, although inducing a more or less higher financial burden [1–3]. The information provided is very useful to policy makers and energy planners in order to design the appropriate policy measures and implement the necessary plans for realizing the most preferred scenario.

However, the way this information is actually perceived and assimilated by the scenario users remains a difficult problem that is usually solved in an informal and highly subjective manner. This is because each scenario presents both advantages and disadvantages and it is impossible to find out a single scenario satisfying all different concerns of policy makers and energy planners. Therefore, for deciding which scenario should form the basis for future actions, it is necessary to resolve the conflicts between competing criteria.

The comparative assessment of alternative actions with respect to multiple conflicting evaluation aspects can be achieved through two different methodological approaches. The first is Multi-Criteria Decision Analysis (MCDA), which is increasingly used to resolve the emerging conflicts, by aggregating either performances or individual preferences in each single criterion by taking into account their relative weights of importance. The action presenting the highest aggregate score or the highest aggregate preference index represents the best compromise among the alternative actions under consideration. Different multicriteria methods have been developed during the last 30 years for providing support to decision makers facing conflicting decision situations. Recent literature surveys have shown that MCDA has been extensively used in energy planning [4,5], with some applications dealing with the comparative assessment of energy scenarios, e.g. [6–8].

On the other side, Cost–Benefit Analysis (CBA) offers an alternative way of synthesizing performances in different evaluation aspects by translating all impact categories into monetary terms. This approach has the advantage of providing results on a scale compatible with the market mechanism and more comprehensible to decision makers.

However, it is very often difficult to express all performances—including impacts on non-traded goods—in monetary terms. Thus, the analysis is often restricted to only monetized aspects such as capital, operation and maintenance costs [9]. The progress made in the assessment of energy-related externalities has recently given an impetus to broaden the range of impacts taken into account, although the emphasis is still given to the analysis of distinct technologies, e.g. [10,11].

The scope of this paper is to implement both methodologies, MCDA and CBA, in order to assess alternative scenarios for the Greek power generation sector, each assuming a different technology mix. The aim is to find out if the increased penetration of renewable energy sources assumed in the environmental scenario provides an attractive balance of economic, technical and environmental points of view. The parallel implementation of the two approaches enables checking the consistency of the obtained results and gaining more confidence in the derived policy signals.

The remainder of the paper is structured as follows: Section 2 includes a short description of the applied methodological tools, Section 3 presents the scenarios for the evolution of the Greek power generation sector and their performances in different evaluation aspects. The results of MCDA and CBA are presented in Section 4, and some concluding remarks are given in Section 5.

2. Methodological approaches

The long identified need to secure a balance between economic, environmental and social targets in the development process cannot be satisfied with the conventional policy making approaches. The inherent complexity of the systems concerned, the uncertainty regarding the consequences of alternative policy choices, the conflict between contradictory values, and the multiplicity of people concerned about policy decisions, advocate the use of powerful decision-aid tools. In particular, MCDA and CBA appear as the most appealing methodological approaches capable of systematically and effectively handling all the above difficulties, each presenting its own strengths and weaknesses. Both methodologies have practically the same ultimate goal: to broaden the evaluation perspective so as to incorporate all aspects that should guide the decision procedure.

2.1. *Multi-criteria decision analysis*

A multiplicity of MCDA methods is currently available for use in a wide variety of decision situations. In this study, the PROMETHEE method was selected because of its simplicity and its capacity to approximate the way human mind expresses and synthesizes preferences in front of multiple contradictory decision perspectives. PROMETHEE I and II methods belong to the wider family of outranking methods and details are given by their developers in [12]. Here, we present briefly the most important of the underlying concepts.

Similarly to all outranking methods, PROMETHEE proceeds to a pairwise comparison of alternatives in each single criterion in order to determine partial binary relations denoting the strength of preference of an alternative a over alternative b. The comparison is made on the initial measurement scale, either quantitative or qualitative and recognizes that human preferences do not pass abruptly from the state of indifference to strict preference, while much uncertainty exists about the limits between these states. Thus, indifference and/or preference thresholds are defined by the decision maker in each

criterion, against which the difference in the scores of each pair of alternatives is compared. The so-obtained partial preference $pi(a,b)$ functions specify the intensity of preference of alternative a over alternative b and take values between 0 and 1, with 1 standing for strict preference and 0 for no preference (including indifference).

A total preference index $P(a,b)$ characterizing any pair of actions over the whole set of criteria is then calculated as the weighted sum of partial preference functions as shown in the following equation:

$$P(a,b) = \sum_i w_i p_i(a,b) \quad with \sum wi = 1$$

The weights vary according to the stakeholder's particular value system and should be interpreted as measures of the degree to which each criterion influences a final statement of whether or not 'alternative a is equal or preferred to b' if all evaluation criteria are taken into account. The sum of preference indices $P(a,i)$ and $P(i,a)$ gives an indication of the degree to which alternative a outranks the other alternatives i, or is outranked by them, respectively. The obtained outranking relations can be exploited for ranking the examined alternatives and identifying the most preferred among them.

2.2. Cost–benefit analysis

Cost–benefit analysis involves the comparison of total costs and benefits associated with a project or policy, namely those reflected in market prices (private cost or benefit) and those experienced by the external economic and natural environment without directly influencing the market mechanism (external cost or benefit). In this sense, CBA constitutes an extension of the conventional financial analysis that is capable of removing market distortions and indicating those actions with the lowest social cost or the highest net social benefit. It is clear that external costs and benefits are not easy to calculate, especially if they refer to non-tradable goods such as environmental quality, human health, biodiversity, etc. These externalities can only be approximated by applying valuation techniques derived from the neoclassical economic theory of welfare or from data derived from relevant studies. In the particular case of energy related externalities, the ExternE project of the EC provides the methodological framework [13] and external cost estimates for energy technologies in different EU countries (for Greece, see [14]).

The time dimension is usually very important in counterbalancing costs and benefits. This is because a project requires a high capital cost to be invested in the first year(s) and provides benefits throughout a long time period. In such a case, it is necessary to calculate the present value of all cost and benefit components by using a suitable discount rate.

Besides the NPV and IRR criteria applied in the conventional financial analysis, the ratio B/C is the most widely used indicator of the profitability of the project from a social point of view, with the value 1 representing the threshold for an acceptable project.

Another option is to calculate the sum of cost and benefit components on an annual basis, with the investment cost reduced to annualized equivalents with the appropriate discount rate. This approach is suitable in our case where the analysis refers to the comparative evaluation of alternative action plans with no specific time allocation of individual projects, while annual cost (or net benefit) figures give a good indication of each plan's attractiveness. In such a case, the plan presenting the lowest cost (or the highest net benefit) is the recommended action.

In any case, sensitivity analysis is usually necessary in order to check the robustness of the results and investigate the impact of the most uncertain parameters.

In CBA, monetary values play the role of weights in MCDA. Whether or not these 'objective' monetary weights coincide with those subjectively placed by individual stakeholders participating in a MCDA procedure depends on the type of impacts considered, the assumptions made and the uncertainties in the estimation of external cost values, the degree to which stakeholders fully understand impacts, the technique used for the derivation of weights and other factors influencing each evaluation method. Nevertheless, it is useful to compare the results from each method and in the case of coinciding rankings, the reliability of the assessment procedure is considerably strengthened.

3. Case study: the Greek power generation sector

3.1. Scenarios for the future

The scenarios considered in this study have been drawn up by official authorities directly or indirectly involved in the design of energy policies in Greece. They are selected so as to represent a wide range of the parameters influencing the evolution of the power generation sector. Specifically, the following scenarios are included in the comparative analysis:

- The Business-as-Usual (BAU) scenario, drawn up by the Regulatory Authority for Energy (RAE) of Greece: it assumes the continuation of recent trends and the completion of the already adopted policy measures.
- The scenario of Public Power Corporation (PPC), which still represents the biggest player in the electricity market: although based on the company's business plan, it covers the whole sector including expected investments of other market players.
- The Climate Change Abatement (CCA) scenario, drawn up by the National Observatory of Athens, the authority responsible for monitoring emissions of greenhouse gases and for establishing the national program for reaching the Kyoto target: it assumes a higher penetration of renewable energy sources (RES) and the contribution of natural gas to the base load.
- The Unsteady Conditions (USC) scenario, drawn up also by RAE: it assumes a faster increase in electricity demand compared to the BAU scenario, while unfavorable geopolitical conditions will impose the intensive exploitation of domestic lignite deposits.

The comparison of these scenarios is made for the year 2010 which is the reference basis in most relevant legislative commitments in the European Union. As shown in Fig. 1, all scenarios assume approximately the same capacity increase between 2000 and 2010. However, the total level of electricity production, as well as the corresponding energy mix present significant differences according to the role assigned to the alternative technologies (Fig. 2).

In particular, as far as RES are concerned, their contribution varies significantly in the examined scenarios. In the BAU and the USC scenarios, additions to RES capacity between 2000 and 2010 amount to 1170 and 950 MW, respectively, with 260 MW representing large hydro-power units. Much higher is the contribution of RES in the other

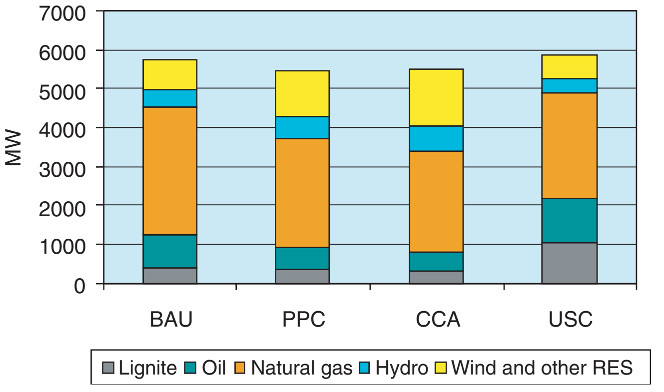

Fig. 1. Capacity increase, 2000–2010.

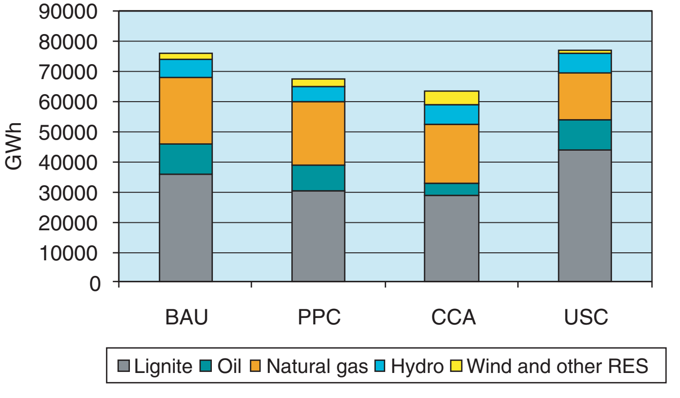

Fig. 2. Composition of electricity mix, 2010.

two scenarios, with the PPC scenario assuming 1720 MW of additional RES capacity and CCA 2120 MW, of which 68% in both cases concern wind power.

It should be noted that none of these scenarios fulfils the obligation of 20.1% of RES contribution provided by the Directive 2001/77/EC for Greece. Their contribution ranges from around 10% in the BAU and USC scenarios to 17.5% in the CCA scenario.

3.2. Evaluation criteria

Besides the legislative limits to RES penetration, it is worth investigating if, there are other arguments advocating the rapid penetration of RES in the power generation sector. For this purpose, the four scenarios are further analyzed with respect to the main policy goals set in the strategies for the electricity sector at both the national and the EC level. More specifically, the considered evaluation criteria fall into the following three categories.

Economic criteria denote the need to strengthen the competitiveness of national economies through the optimal allocation of financial resources and the reduction of the

cost imposed on electricity consumers. The performances of the following criteria are calculated on the basis of data provided in [15]:

The total investment cost (M€) for the capacity increase up to 2010 (neglecting time distribution of investments).

The full electricity production cost (€/MW h) including initial investment reduced with a discount rate of 8%, depreciations, fuel, operational and maintenance costs (assuming Brent oil price equal to 38$/bl).

Technical criteria reflect the concern for the availability and security of electricity supply and include:

- The energy (MW h) that can be produced with 100% certainty in low hydrological periods and with a conservative prediction for wind power. For this purpose, in the case of large hydro-power plants, the lowest load factor recorded in the last 10 years (0.112) is used to calculate the expected production. For small hydro-and wind-power units, the conservative load factors used amount to 0.228 and 0.28, respectively, and are derived by the assumptions of RAE and of the Hellenic Transmission System Operator [15].
- The ability to respond to peak load (MW) is calculated by assigning a factor of 1 to the installed capacity of gas, oil and large hydro-units, 0.5 to lignite capacity (used normally at base load and not able to quickly respond to higher demand during peak hours) and 0 to wind and small hydro.
- The security of the system's supply, reflecting mostly geopolitical factors that could affect the continuous availability of non-renewable energy carriers from their origin and measured on a qualitative scale. The value for each scenario results as the weighted average of the electricity mix with the value of 100 assigned to domestic lignite and RES, 40 to gas and 20 to oil.

Environmental criteria reflect the need to protect the natural environment in compliance with the country's international commitments. Based on a common set of emission factors in all scenarios (used for establishing emissions inventories in Greece), the following criteria have been calculated:

- The percentage increase (%) in CO_2 emissions—the most important greenhouse gas—expected in 2010 compared to the 1990 level.
- The annual SO_2 and NO_x emissions (kt) which are the main contributors to acidification and are responsible for serious damage to human health and ecosystems. According to Directive 2001/81/EC, EU countries have to restrict these emissions so as to reach the national targets set for 2010.

The performances of the examined scenarios presented in Table 1 illustrate the conflict in the policy targets implied by the above criteria. It can be seen, for example, that the BAU scenario presents the lowest investment cost and the second lowest operational cost. However, these cost savings are achieved at the expense of environmental quality. Similarly, the USC scenario performs best in the technical criteria but is associated with a much higher investment cost and also with lower environmental performances. This means that the full satisfaction of all policy goals is not feasible and that policy makers have to find out a compromise solution representing the most acceptable balance between their competing aspirations. The design of energy policies is therefore a complicated task in that

Table 1
Evaluation matrix of the four alternative scenarios, 2010

Criteria	BAU	PPC	CCA	USC
Investment cost (M€ 2004)	5138	5323	5447	6020
Production cost (€/MW h)	52.38	52.36	53.03	53.13
Guaranteed energy (GW h)	73,130	66,830	60,260	74,390
Available power during peak load (MW)	12,793	12,416	12,122	12,789
Security of supply (qualitative)	72	70.9	76.3	77.2
CO_2 increase (% 1990)	69.8	48.0	30.8	86.5
SO_2 emissions (kt)	466	398	322	541
NO_x emissions (kt)	90	77	67	102

policy makers and other stakeholders have to decide the degree to which they are willing to give up in one policy target in order to improve one or more other performances.

4. Results

4.1. Multi-criteria decision analysis

The conflicts associated with electricity expansion planning have first been resolved by means of a multicriteria evaluation of the examined scenarios with the PROMETHEE method. In order to check the sensitivity of rankings with varying preferences of the concerned stakeholders, four different sets of weights have been used: Set 1 assumes equal importance of the three categories of criteria, set 2 assigns 50% of importance to economic criteria, while in sets 3 and 4, 50% is attributed to the technical and environmental criteria, respectively. In all cases, the total weight assigned to a category is equally distributed among the corresponding criteria.

Indifference and preference thresholds (see Section 2.1) are defined for all criteria as percentages of the impact range, i.e. of the difference between the highest and the lowest score. The former is set at 10%, denoting that if the difference in the performance of two scenarios a and b in a criterion is lower than this threshold, these are considered as equivalent ($p(a,b) = 0$). Correspondingly, the preference threshold is set at 25% of the impact range, denoting that strict preference ($p(a,b) = 1$) of scenario a over scenario b holds only if the difference in their performance of scenario is higher than this threshold.

Table 2 presents the rankings provided by the PROMETHEE method for each set of weights. The indices shown in this table quantify the degree to which each scenario outranks (positive value) or is outranked (negative value) by the others and sum up to zero. It can be seen that independently of the weights of the criteria under consideration, the CCA scenario represents the optimal balance between economic, technical and environmental criteria. The second most preferred scenario for all weighting sets is the PPC scenario, followed by the BAU scenario and, in the last place, by the USC scenario.

The difference between the obtained rankings consists in the relative deviation between the outranking indices characterizing each scenario. More specifically, in S_2 and S_3 the values of the outranking indices approach to each other because of the higher weight attributed to economic and technical criteria, respectively, indicating that the relative

Table 2
Outranking indices of scenarios for different weighting sets Si

Scenario	S_1	S_2	S_3	S_4
CCA	0.19	0.12	0.13	0.26
PPC	0.05	0.05	0.04	0.07
BAU	−0.06	−0.04	−0.04	−0.09
USC	−0.18	−0.13	−0.13	−0.24

superiority of the CCA scenario is reduced. In the opposite case, a higher weight assigned to environmental criteria further amplifies its strength.

It is obvious, that the overall performance and the corresponding rank of the examined scenarios are closely linked to the contribution of RES. As already mentioned, the first ranked CCA scenario assumes 2120 MW of additional RES capacity between 2000 and 2010, followed by the PPC scenario with 1720 MW. On the other hand, the low RES capacity supposed in BAU and USC scenarios is also reflected in their placement at the bottom of the obtained ranking.

4.2. Cost–benefit analysis

For applying the Cost–Benefit methodology, the criteria performances should be translated into monetary terms. The values assigned to each non-economic criterion rely on the following considerations and/or assumptions:

- Guaranteed energy supply: assuming that the scenario with the highest score (USC) induces zero external cost, the deviation of the other three scenarios from this upper value is multiplied by the cost of imported electricity. The unit cost considered is assumed to amount o 30 €/MW h, which is the cost actually paid for electricity imports (mainly from the neighboring Balkan countries).
- Available power during peak load: assuming that the scenario with the highest score (BAU) induces zero external cost, the deviation of the other three scenarios from this upper value is multiplied by the production cost characterizing back-up units working at 0.15 load factor. These units are assumed to use natural gas in combined cycle technology and have a 50% higher production cost than the normal cost of such units in Greece, due to the lower capacity factor.
- CO_2 emissions: the percentage increase in all scenarios is higher than the Kyoto target of 25% and the expected number of allowances to be allocated to the power generation sector for the 2nd commitment period 2008–2012. This deviation is valued at 10 CO_2 which is a rather optimistic price for the market of emissions allowances.
- SO_2 and NO_x emissions: the external cost estimates assigned to these emissions are equal to 4000 €/t SO_2 $_{\kappa\alpha\iota}$ 5000 €/t NO_x and are based on the range of values calculated in the ExternE project [14] which refer mostly to the impact on human health.

The investment cost presented in Table 1, although constituting a discrete evaluation criterion reflecting the amount of capital bound, is here considered only in its annualized form as is included in the operational cost of each scenario. Moreover, the criterion

Table 3
Social cost components of the examined scenarios for the year 2010

Cost components (M€/year)	BAU	PPC	CCA	USC
Private production cost	3966	3538	3364	4097
Cost of electricity deficit	38	227	424	0
Cost of peak power deficit	0	40	71	0
Cost of CO_2 emission allowances	288	198	127	357
External cost of SO_2 emissions	1862	1593	1287	2164
External cost of NO_x emissions	448	385	333	512
Total social cost	448	5981	5606	7130

'security of supply' is not taken into consideration in the CBA because such external cost estimates are at the moment not available. It should be noted that all cost components are reduced on an annual basis for the reference year 2010 by taking into account the total electricity generation assumed in each scenario, as shown in Table 3 together with the results of the CBA.

It can be seen that the CCA scenario presents the lowest annual private cost mainly because of the lower amount of generated electricity, followed by the PPC scenario. These two scenarios appear as equivalent if the cost increases due to electricity and power deficit are taken into account. On the other hand, the BAU and USC scenarios are characterized by a very high private cost that is not counterbalanced by their superiority with respect to electricity and load supply sufficiency. The cost difference becomes much bigger if the external cost assigned to the environmental criteria is taken into account. It can be seen that especially the SO2 related externalities represent a considerable part of the total social cost of electricity production in Greece. These emissions are primarily owed to lignite fired power plants because of the high sulfur content of domestic lignite deposits. Thus, in total, the CCA scenario appears as the most economical scenario if the total cost imposed on society by electricity generation is the basis of cost comparisons.

The cost deviation between CCA and PPC originates from the difference in the external cost attributed to atmospheric emissions. This means that it is principally the increased RES capacity of the CCA scenario that shifts it to first place of the CBA ranking.

The obtained results are confirmed by sensitivity analysis in terms of the following uncertain parameters that are changed one by one with respect to the basic CBA assumptions:

- The cost of electricity imports increases to 50 €/MW h.
- The cost of purchasing CO_2 emission allowances increases to 20 €/t CO_2.
- The external cost of SO_2 and NO_x emissions decreases by 50% compared to the basic estimates following the trend observed in the results of other countries with recent developments in the ExternE methodology. Thus, the unit external cost amounts to the very optimistic estimate of 2000 €/t SO_2 and 2500 €/t NO_x.

The results of the sensitivity analysis are summarized in Table 4. It can be seen that the rank order of scenarios does not change from that derived with the basic CBA assumptions. The social cost of the CCA scenario is by 200–450,000€/year lower than the second best PPC scenario, while the cost difference with the BAU scenario amounts to

Table 4
Sensitivity analysis of CBA parameters (M€/year)

Scenario	Basic assumptions	Cost of imp. electricity, 50 €/MW h	Cost of CO_2 allowances, 20 €/MW h	External cost of SO_2 and NO_x, 50% of basic ass.
CCA	5606	5888	5732	4796
PPC	5981	6132	6179	4992
BAU	6601	6627	6889	5446
USC	7130	7130	7486	5792

650–1,160,000€/year. As expected, the social cost of the USC scenario is the highest in all the sensitivity analyses. It follows, that policy makers should strive to shift away from the trends of the past assumed in the BAU scenario and try to implement the CCA scenario by promoting policies and measures encouraging the wide penetration of RES and other clean electricity technologies in the Greek electricity generation system. Moreover, it is an imperative need to avoid the unsteady conditions assumed in the USC scenario or to deal with them with the systematic deployment of RES, instead of reverting back to the intensive exploitation of lignite.

5. Concluding remarks

The scope of this paper was to comparatively evaluate four scenarios for the development of the power generation sector in Greece, each assuming a different energy mix and a different contribution of RES. The scenarios have been developed by official authorities and represent alternative pathways to meet electricity demand in the country. The Business-as-Usual (BAU) scenario reflects a long-lasting attachment to conventional fuels with natural gas considered as the principal means of complying with environmental obligations. The USC scenario represents an even more conservative vision for electricity generation which further amplifies the role of lignite in order to cope with unsteady conditions in the energy market and especially with problems in the regular supply of natural gas from Russia. Both scenarios are assigning only a minor role to RES, their total share varying around 10%. The scenario drawn up by PPC assumes the restriction of the electricity derived from lignite together with a higher penetration of RES units, although their contribution to electricity generation is rather underestimated. Finally, the scenario for combating climate change is the most optimistic regarding the deployment of RES, although the natural gas is here again the dominant fuel in the system's expansion.

As expected, the analysis of the associated impacts reveals considerable conflicts between economic, technical and environmental aspects. Each scenario has both its strong and weak points that are usually treated in a unilateral or instinctive way, either in literature or in practice. Regarding RES, and depending on the particular viewpoint of the analyst, their environmental benefits are very often appreciated but concern about possible financial burdens usually impedes their wide exploitation.

The analysis performed in this paper aims at the parallel implementation of two increasingly used decision support techniques, multicriteria decision analysis and cost–benefit analysis. Originating from a different methodological background, both

approaches succeed in broadening the evaluation perspective and aggregate in a single indicator the overall performance of each alternative scenario. Taking into account that each method separately is often disputed because of the uncertainties emanating from the several less tangible aspects included in the analysis, the coincidence of the obtained results is mutually increasing the confidence in their capacity and reliability.

In the case study under consideration, it is found that the scenario with the highest contribution of RES represents the most attractive configuration of the electricity generation system in Greece. Since natural gas has in all the scenarios—except the USC—approximately the same share, it can be deduced that the strength of the CCA scenario is principally linked to the strong role assigned to RES. Thus, besides their valuable assistance in complying with the commitments for greenhouse gas emissions and acid atmospheric pollutants, RES are proved to secure the best balance of economic, technical and environmental considerations and the sustainable development of the power generation system.

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